

Emergency Power System Unreliability

1998–2009

1 INTRODUCTION

This report presents an unreliability evaluation of the emergency power system (EPS) at 104 U.S. commercial nuclear power plants listed in Table 1. For each plant the corresponding Standardized Plant Analysis Risk (SPAR) model (version model indicated in Table 1) was used in the yearly calculations. Demand, run hours, and failure data from fiscal year (FY) 1998 through FY 2009 for selected components in the EPS were obtained from the Equipment Performance and Information Exchange (EPIX) database. Train unavailability data (outages from test or maintenance) were obtained from the Reactor Oversight Process (ROP) Safety System Unavailability (SSU) database (FY 1998–FY 2001) and the Mitigating Systems Performance Index (MSPI) database (FY 2002–FY 2009). Common-cause failure (CCF) data used in the models are from the 2005 update to the CCF database.

Table 1. Plant EPS Class listing.

| Class | Plant | Version | Class | Plant | Version | Class | Plant | Version |
|---------|-----------------|---------|---------|------------------|---------|---------|------------------|---------|
| Class 2 | Brunswick 1 | 3.31 | Class 2 | Wolf Creek | 3.31 | Class 3 | San Onofre 3 | 3.21 |
| Class 2 | Brunswick 2 | 3.31 | Class 3 | Arkansas 1 | 3.31 | Class 3 | Sequoyah 1 | 3.31 |
| Class 2 | Callaway | 3.31 | Class 3 | Arkansas 2 | 3.31 | Class 3 | Sequoyah 2 | 3.31 |
| Class 2 | Clinton 1 | 3.31 | Class 3 | Beaver Valley 1 | 3.31 | Class 3 | South Texas 1 | 3.21 |
| Class 2 | Columbia 2 | 3.31 | Class 3 | Beaver Valley 2 | 3.31 | Class 3 | South Texas 2 | 3.21 |
| Class 2 | Comanche Peak 1 | 3.31 | Class 3 | Braidwood 1 | 3.31 | Class 3 | St. Lucie 1 | 3.31 |
| Class 2 | Comanche Peak 2 | 3.31 | Class 3 | Braidwood 2 | 3.31 | Class 3 | St. Lucie 2 | 3.32 |
| Class 2 | Cook 1 | 3.32 | Class 3 | Byron 1 | 3.31 | Class 3 | Surry 1 | 3.31 |
| Class 2 | Cook 2 | 3.32 | Class 3 | Byron 2 | 3.31 | Class 3 | Surry 2 | 3.31 |
| Class 2 | Cooper | 3.31 | Class 3 | Calvert Cliffs 1 | 3.21 | Class 3 | Susquehanna 1 | 3.31 |
| Class 2 | Crystal River 3 | 3.32 | Class 3 | Calvert Cliffs 2 | 3.21 | Class 3 | Susquehanna 2 | 3.31 |
| Class 2 | Davis-Besse | 3.31 | Class 3 | Catawba 1 | 3.32 | Class 3 | Three Mile Isl 1 | 3.31 |
| Class 2 | Duane Arnold | 3.31 | Class 3 | Catawba 2 | 3.32 | Class 3 | Turkey Point 3 | 3.31 |
| Class 2 | Fort Calhoun | 3.31 | Class 3 | Diablo Canyon 1 | 3.31 | Class 3 | Turkey Point 4 | 3.31 |
| Class 2 | Ginna | 3.31 | Class 3 | Diablo Canyon 2 | 3.31 | Class 3 | Vogtle 1 | 3.31 |
| Class 2 | Grand Gulf | 3.31 | Class 3 | Farley 1 | 3.31 | Class 3 | Vogtle 2 | 3.31 |
| Class 2 | Harris | 3.31 | Class 3 | Farley 2 | 3.31 | Class 3 | Watts Bar 1 | 3.21 |
| Class 2 | Kewaunee | 3.31 | Class 3 | Hatch 1 | 3.31 | Class 4 | Browns Ferry 1 | 3.21 |
| Class 2 | McGuire 1 | 3.31 | Class 3 | Hatch 2 | 3.31 | Class 4 | Browns Ferry 2 | 3.21 |
| Class 2 | McGuire 2 | 3.31 | Class 3 | Hope Creek | 3.21 | Class 4 | Browns Ferry 3 | 3.21 |
| Class 2 | Monticello | 3.31 | Class 3 | Indian Point 2 | 3.31 | Class 4 | Dresden 2 | 3.31 |
| Class 2 | Nine Mile Pt. 1 | 3.21 | Class 3 | Indian Point 3 | 3.31 | Class 4 | Dresden 3 | 3.31 |
| Class 2 | Nine Mile Pt. 2 | 3.21 | Class 3 | La Salle 1 | 3.31 | Class 4 | Fermi 2 | 3.31 |
| Class 2 | Oconee 1 | 3.31 | Class 3 | La Salle 2 | 3.31 | Class 4 | FitzPatrick | 3.31 |
| Class 2 | Oconee 2 | 3.31 | Class 3 | Millstone 2 | 3.21 | Class 4 | Limerick 1 | 3.21 |
| Class 2 | Oconee 3 | 3.31 | Class 3 | Millstone 3 | 3.21 | Class 4 | Limerick 2 | 3.21 |
| Class 2 | Oyster Creek | 3.31 | Class 3 | Palo Verde 1 | 3.31 | Class 4 | North Anna 1 | 3.31 |
| Class 2 | Palisades | 3.31 | Class 3 | Palo Verde 2 | 3.31 | Class 4 | North Anna 2 | 3.31 |
| Class 2 | Perry | 3.31 | Class 3 | Palo Verde 3 | 3.31 | Class 4 | Point Beach 1 | 3.31 |
| Class 2 | Pilgrim | 3.31 | Class 3 | Peach Bottom 2 | 3.31 | Class 4 | Point Beach 2 | 3.31 |
| Class 2 | Robinson 2 | 3.31 | Class 3 | Peach Bottom 3 | 3.31 | Class 4 | Prairie Island 1 | 3.31 |
| Class 2 | Seabrook | 3.21 | Class 3 | River Bend | 3.31 | Class 4 | Prairie Island 2 | 3.31 |
| Class 2 | Summer | 3.32 | Class 3 | Salem 1 | 3.22 | Class 4 | Quad Cities 1 | 3.31 |
| Class 2 | Vermont Yankee | 3.31 | Class 3 | Salem 2 | 3.22 | Class 4 | Quad Cities 2 | 3.31 |
| Class 2 | Waterford 3 | 3.31 | Class 3 | San Onofre 2 | 3.21 | | | |

This report does not attempt to estimate basic event values for use in a probabilistic risk assessment (PRA). Suggested values for such use are presented in the report, *Industry-Average*

Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, [NUREG/CR-6928](#) (Reference 1). Baseline EPS unreliability results using basic event values from that report are summarized in Section 3. Trend results for EPS (using system-specific data) are presented in Section 4. Similar to previous system study updates, Section 5 contains importance information (using the baseline results from Section 3), and Section 7 describes the EPS.

The EPS was grouped into three classes based on design considerations and configurations. Class 2 EPS includes configurations that effectively result in a success criterion of one of two EDGs (or other emergency power sources). Class 3 EPS includes configurations that effectively result in a success criterion of one of three EDGs (or other emergency power sources). EPS designs effectively resulting in a success criterion of one of four or more are included in Class 4. Table 1 summarizes the plants and their classes.

The EPS model is evaluated using the loss of offsite power (LOOP) flag set in the SPAR model. The LOOP flag set assumes all ac power is unavailable and that the EPS system is required to perform to mitigate the effects of the LOOP initiating event. All models include failures due to unavailability while in test or maintenance. Human error has not been included in the SPAR model logic. An overview of the trending methods, glossary of terms, and abbreviations can be found in the [Overview and Reference](#) document on the Reactor Operational Experience Results and Databases web page.

Two modes of the models for the EPS system are calculated. The EPS start-only model is the SPAR EPS model modified by setting all fail-to-run basic events to zero (False), setting unit cross-tie events to False, setting all recovery events to False, and setting all cooling basic events to False. The 8-hour mission model includes all basic events in the EPS SPAR model.

2 SUMMARY OF FINDINGS

The results of this EPS system unreliability study are summarized in this section. Of particular interest is the existence of any statistically significant¹ increasing trends. In this update, no statistically significant increasing trends were identified in the EPS unreliability trend results.

This update also identified no statistically significant decreasing trends in the EPS results.

The industry-wide EPS start-only and 8-hour basic event group importances were evaluated and are shown in Figure 5. In both cases, the leading contributors to EPS system unreliability are the 1E Generator group of basic events, generator auxiliary equipment, and special events. Cooling and the cross-tie to another unit were also important for the 8-hour mission model only.

3 INDUSTRY-WIDE UNRELIABILITY

The EPS fault trees from the SPAR models were evaluated for each of the 104 operating U.S. commercial nuclear power plants.

¹ Statistically significant is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

The industry-wide unreliability of the EPS has been estimated for two modes of operation. A start-only model and an 8-hour mission model were evaluated, see Table 2. The uncertainty distributions for the EPS classes include both plant design variability (within a class) and parameter uncertainty while using industry-wide component failure data (FY 1998–FY 2002)². Table 2 shows the percentiles and mean of the aggregated sample data (Latin hypercube, 1000 samples for each model) collected from the uncertainty calculations of the EPS fault trees in the SPAR models. In Figure 1 and Figure 2, the 5th and 95th percentiles and mean point estimates are shown each class and for the industry.

Table 2. Industry-wide unreliability values.

| Model | EPS Grouping | Lower (5%) | Median | Mean | Upper (95%) |
|----------------|--------------|------------|----------|----------|-------------|
| Start-Only | Industry | 3.62E-07 | 4.45E-05 | 2.52E-04 | 1.19E-03 |
| | Class 2 | 9.38E-06 | 3.11E-04 | 5.74E-04 | 1.97E-03 |
| | Class 3 | 9.66E-07 | 2.22E-05 | 9.82E-05 | 4.36E-04 |
| | Class 4 | 1.15E-09 | 6.37E-06 | 3.28E-05 | 1.49E-04 |
| 8-hour Mission | Industry | 1.01E-05 | 3.17E-04 | 9.03E-04 | 3.50E-03 |
| | Class 2 | 7.22E-05 | 1.38E-03 | 1.86E-03 | 5.21E-03 |
| | Class 3 | 2.40E-05 | 1.95E-04 | 4.65E-04 | 1.80E-03 |
| | Class 4 | 9.46E-07 | 3.86E-05 | 1.98E-04 | 1.01E-03 |

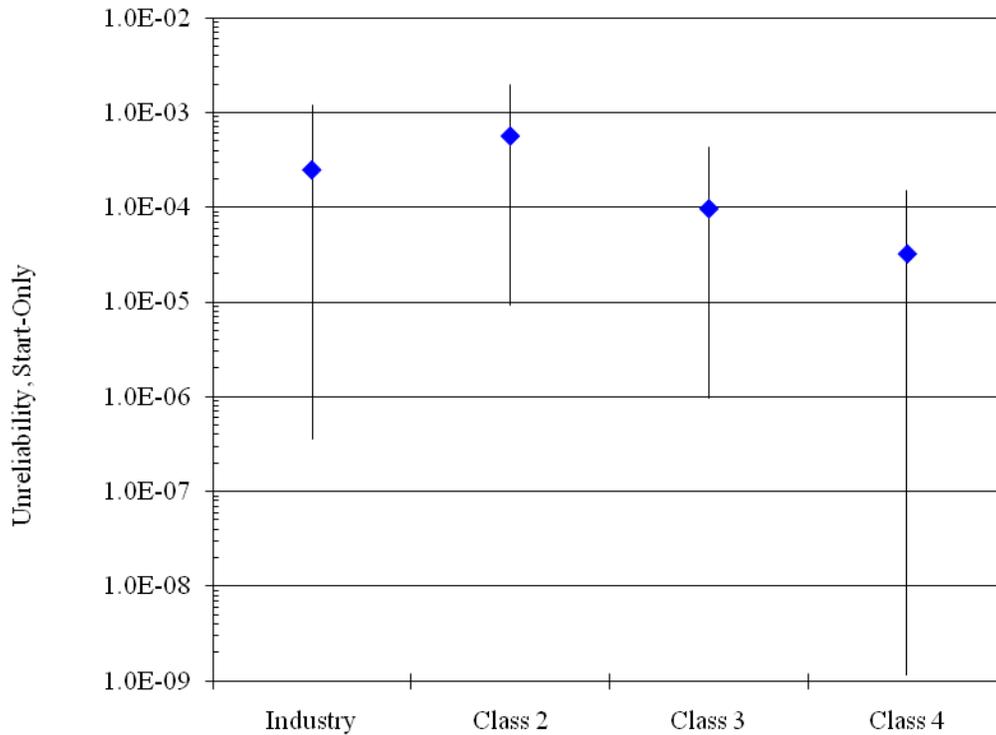


Figure 1. EPS start-only mission unreliability for Class 2, 3, and 4 and industry-wide groupings.

² By using industry-wide component failure data, individual plant performance is not included in the distribution of results.

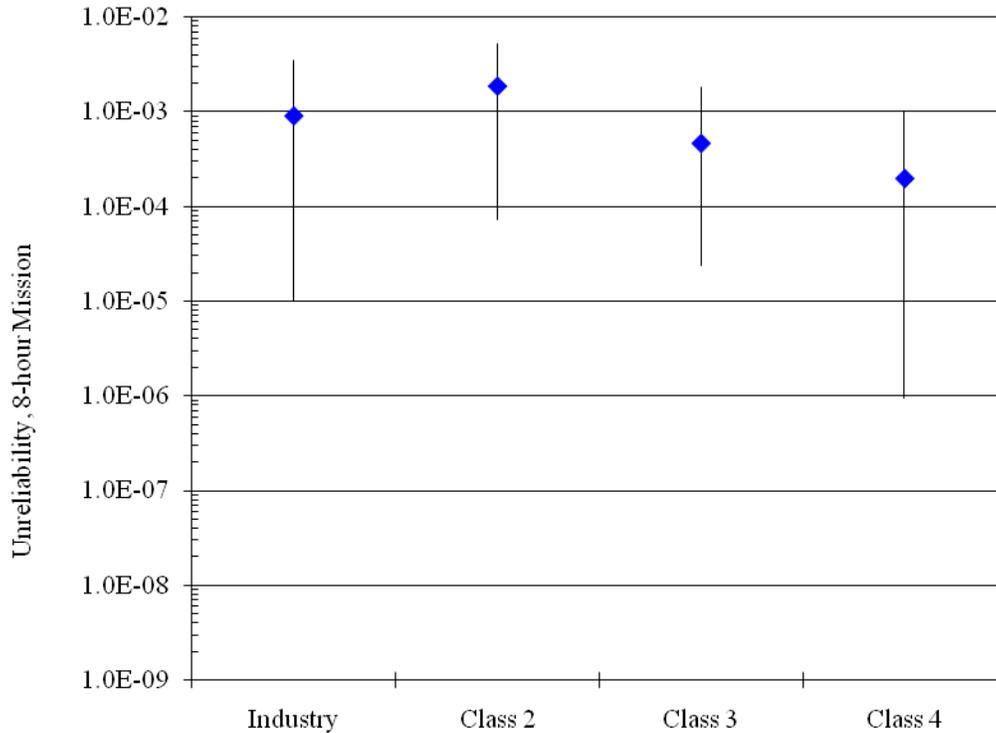


Figure 2. EPS 8-hour mission unreliability for Class 2, 3, and 4 and industry-wide groupings.

4 INDUSTRY-WIDE TRENDS

The yearly (FY 1998–FY 2009) failure and demand or run time data were obtained from EPIX for the EPS system. EPS train maintenance unavailability data for trending are from the same time period, as reported in the ROP and EPIX. The component basic event uncertainty was calculated for the EPS system components using the trending methods described in Section 1 and 2 of the [Overview and Reference](#) document. Table 6 and Table 7 show the yearly data values for each EPS system specific component and failure mode combination that was varied in the model. These data were loaded into the EPS system fault tree in each SPAR model with an EPS system (see Table 1).

The trend charts show the results of varying component reliability data over time and updating generic, relatively flat prior distributions using data for each year. In addition, for comparison, this update (current SPAR/EPIX) is shown. Section 4 of the [Overview and Reference](#) link on the System Studies main web page provides more detailed discussion of the trending methods. In the lower left hand corner of the trend figures, the regression method is reported.

The components and failure modes that were varied in the EPS model are:

- EPS diesel generator start, run, and test and maintenance.

Figure 3 shows the trend in the EPS start-only model unreliability. Table 4 shows the data points for Figure 3. No statistically significant trends within the industry-wide estimates of EPS system unreliability (FTS) on a per fiscal year basis were identified.

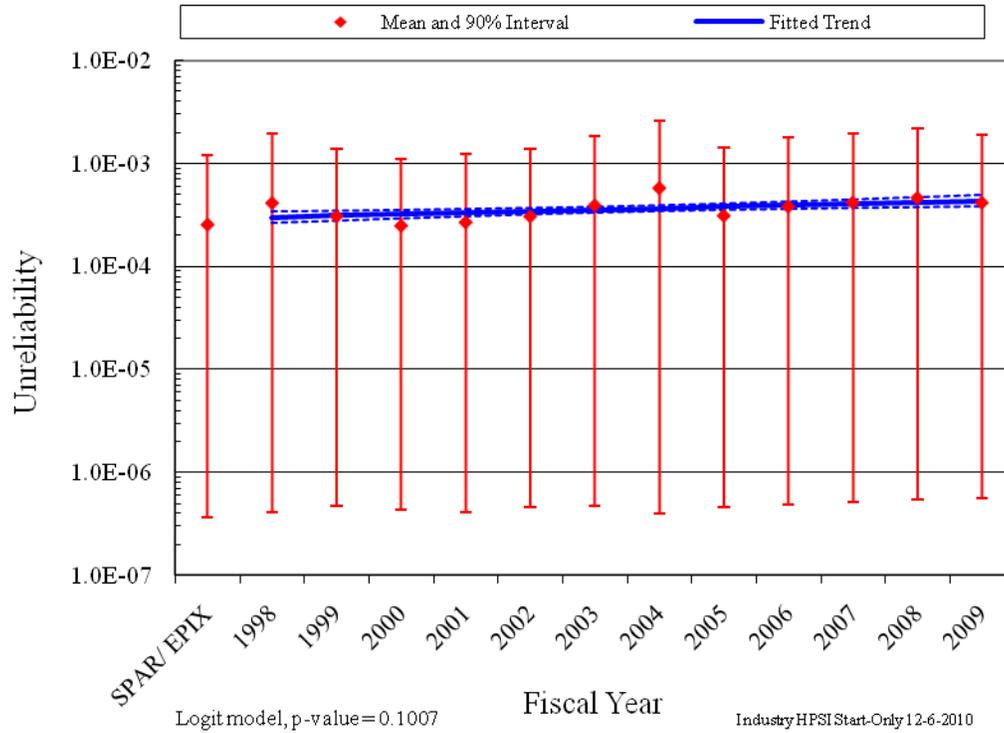


Figure 3. Trend of EPS system unreliability (start-only model), as a function of fiscal year.

Figure 4 shows the trend in the 8-hour mission unreliability. No statistically significant trend within the industry-wide estimates of EPS system unreliability (8-hour mission) on a per fiscal year basis was identified. Table 5 shows the data points for Figure 4.

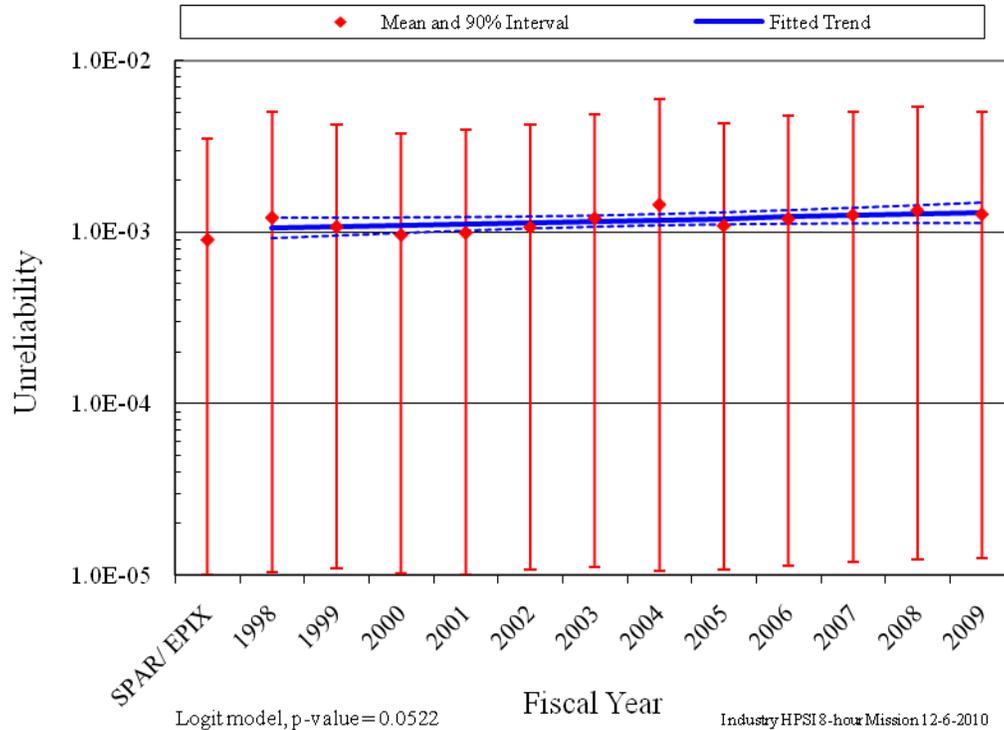


Figure 4. Trend of EPS system unreliability (8-hour model), as a function of fiscal year.

5 BASIC EVENT GROUP IMPORTANCES

The EPS basic event group Fussell-Vesely importances were calculated for the FTS and 8-hour model for each plant using the industry-wide data (1998–2002). These basic event group importances were then averaged across all plants to represent an industry-wide basic event group importance. The industry-wide EPS start-only and 8-hour basic event group importances are shown in Figure 5. In both cases, the leading contributors to EPS system unreliability are the 1E Generator group of basic events, generator auxiliary equipment, and special events. Cooling and the cross-tie to another unit were also important for the 8-hour mission model only. For more discussion on the EPS diesel generators, see the emergency diesel generator component reliability study at [NRC Reactor Operational Experience Results and Databases](#). Table 3 shows the SPAR model EPS importance groups and their descriptions.

The basic event group importances were also averaged across plants of the same EPS class to represent class basic event group importances. The class EPS start-only and 8-hour basic event group importances are shown in Figure 6, Figure 7, and Figure 8. In both cases, for all classes, the leading contributor to EPS system unreliability is the 1E Generator group of basic events.

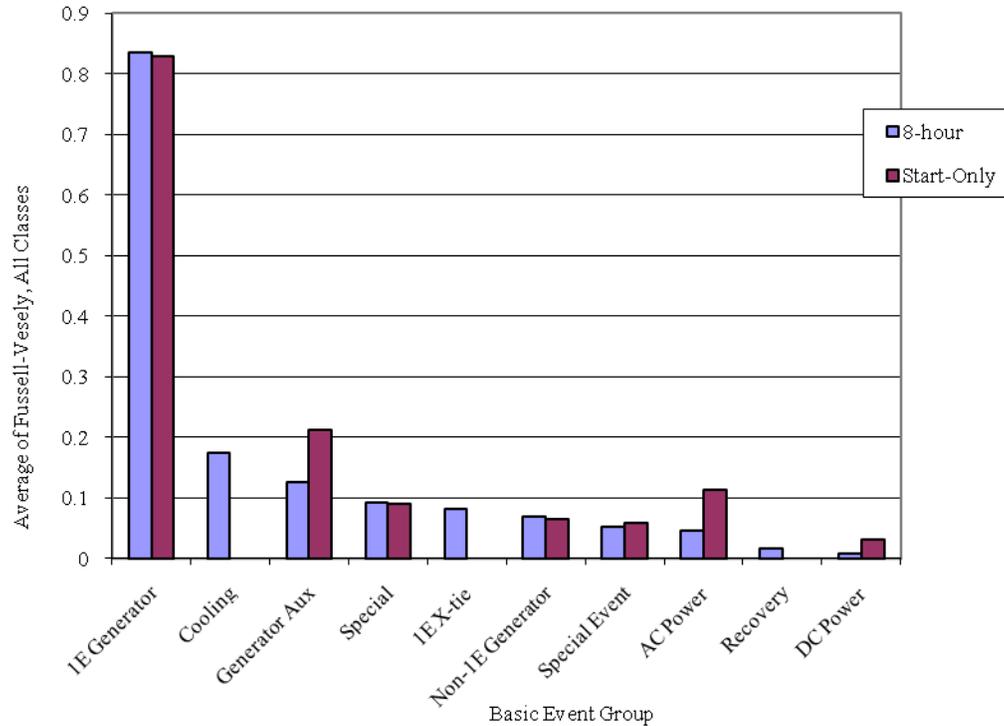


Figure 5. EPS industry-wide basic event group importances.

Table 3. EPS model basic event importance group descriptions.

| Group | Description |
|------------------|---|
| IE Generator | All basic events associated with the primary emergency power supplies. Includes diesel, gas turbine, and hydro powered equipment. The start, run, common-cause, and test and maintenance are included in this group of basic events. |
| IE X-tie | Cross-tie or swing IE qualified generating equipment available to the EPS in the model. |
| AC Power | Buses and circuit breakers in the EPS model. |
| Cooling | Cooling support components: service water or component cooling pumps, valves, and heat exchangers. |
| DC Power | Buses, circuit breakers, battery chargers, and batteries in the EPS model. |
| Generator Aux | This group includes the emergency power auxiliary components that are explicitly modeled in the EPS system. Includes the fuel oil, starting air, room cooling, and electrical dedicated to the generators. |
| Non IE Generator | All basic events associated with the secondary emergency power supplies. Includes diesel, gas turbine, and hydro powered equipment. The start, run, common-cause, and test and maintenance are included in the group of basic events. |
| Recovery | This group contains the events that allow operator recovery from expected automatic actions. |
| SBO Generator | These are all the various types of alternate power supplies: Diesel generators, combustion-turbines, and hydro-turbines. |
| Special Event | These are various special events that are added to the model to model plant-specific conditions that affect the EPS. |

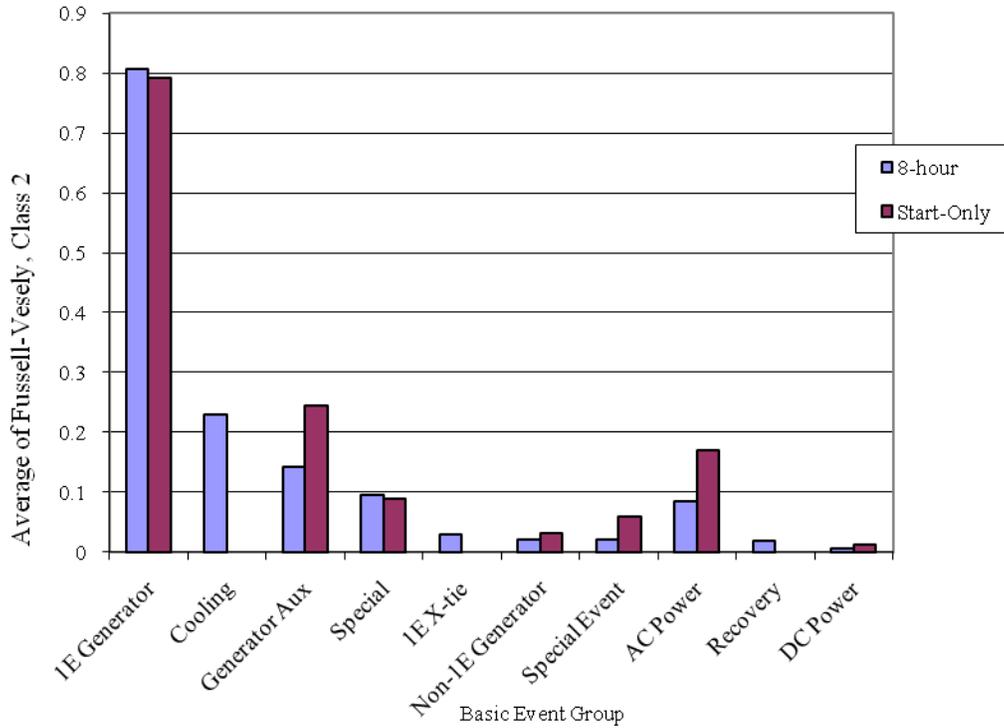


Figure 6. EPS Class 2 basic event group importances.

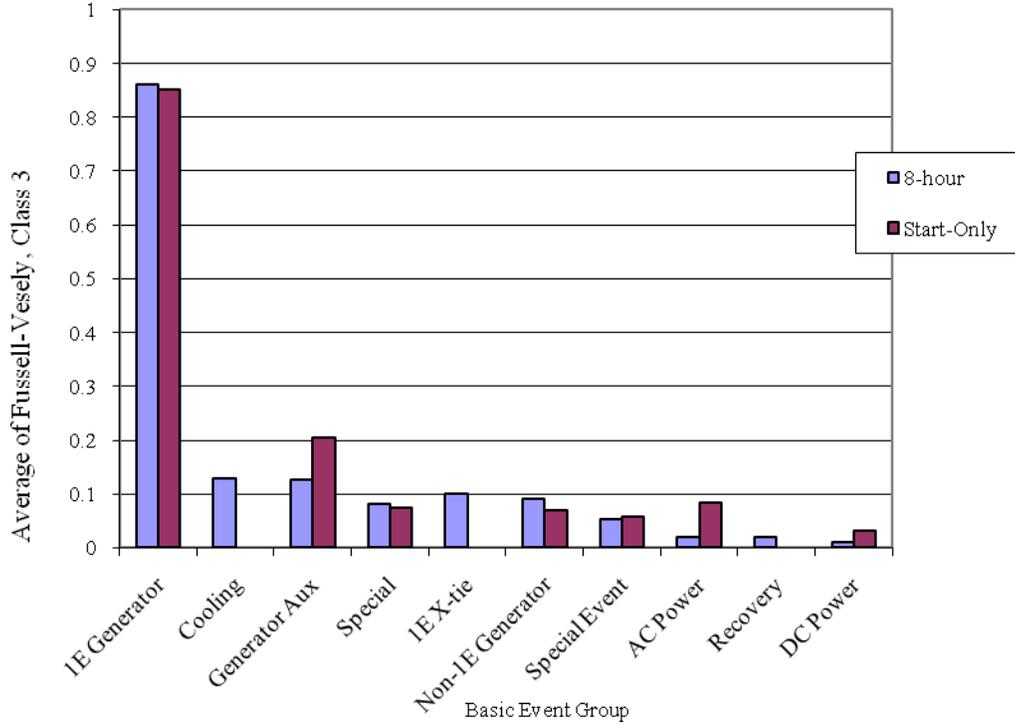


Figure 7. EPS Class 3 basic event group importances.

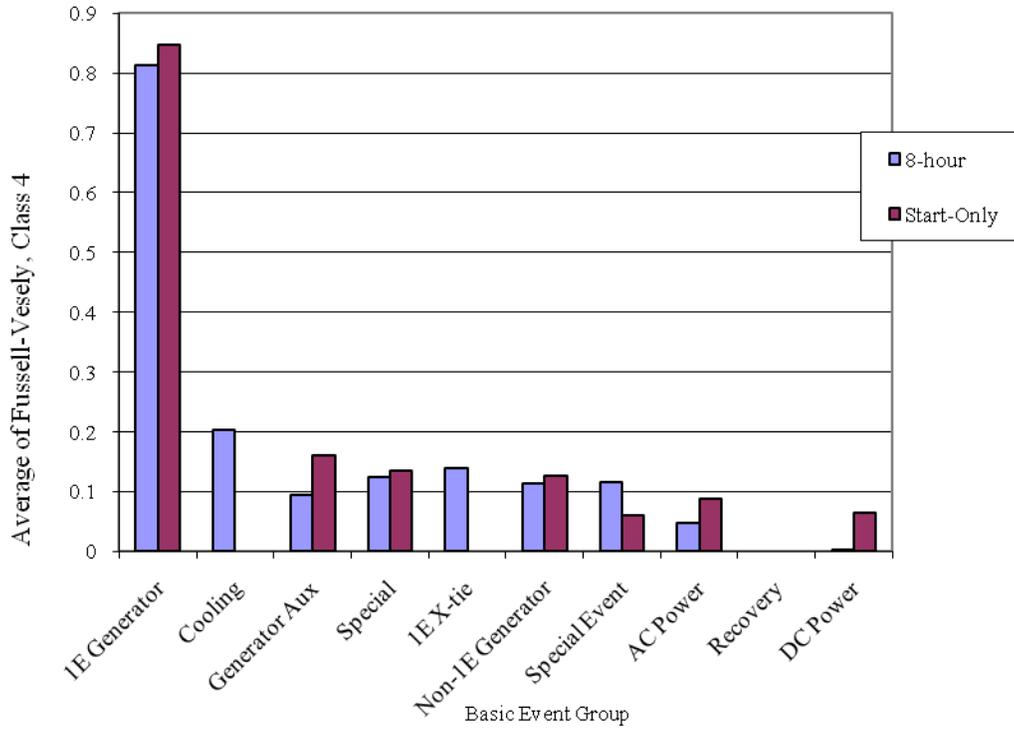


Figure 8. EPS Class 4 basic event group importances.

6 DATA TABLES

Table 4. Plot data for EPS start-only trend, Figure 3.

| FY/Source | Regression Curve Data Points | | | Plot Trend Error Bar Points | | |
|------------|------------------------------|---------------|----------------|-----------------------------|----------------|----------|
| | Mean | Lower (5%) | Upper (95%) | Lower (5%) | Upper (95%) | Mean |
| SPAR/ EPIX | | | | 3.62E-07 | 1.19E-03 | 2.52E-04 |
| 1998 | 3.01E-04 | 2.62E-04 | 3.45E-04 | 4.09E-07 | 1.93E-03 | 4.09E-04 |
| 1999 | 3.11E-04 | 2.76E-04 | 3.50E-04 | 4.75E-07 | 1.38E-03 | 3.04E-04 |
| 2000 | 3.21E-04 | 2.90E-04 | 3.56E-04 | 4.32E-07 | 1.09E-03 | 2.46E-04 |
| 2001 | 3.32E-04 | 3.04E-04 | 3.63E-04 | 4.09E-07 | 1.22E-03 | 2.66E-04 |
| 2002 | 3.44E-04 | 3.17E-04 | 3.72E-04 | 4.60E-07 | 1.39E-03 | 3.03E-04 |
| 2003 | 3.55E-04 | 3.30E-04 | 3.82E-04 | 4.69E-07 | 1.84E-03 | 3.88E-04 |
| 2004 | 3.67E-04 | 3.41E-04 | 3.95E-04 | 4.00E-07 | 2.57E-03 | 5.70E-04 |
| 2005 | 3.80E-04 | 3.51E-04 | 4.11E-04 | 4.61E-07 | 1.42E-03 | 3.08E-04 |
| 2006 | 3.93E-04 | 3.59E-04 | 4.30E-04 | 4.84E-07 | 1.79E-03 | 3.78E-04 |
| 2007 | 4.06E-04 | 3.66E-04 | 4.50E-04 | 5.16E-07 | 1.95E-03 | 4.12E-04 |
| 2008 | 4.20E-04 | 3.73E-04 | 4.73E-04 | 5.41E-07 | 2.18E-03 | 4.58E-04 |
| 2009 | 4.34E-04 | 3.79E-04 | 4.98E-04 | 5.56E-07 | 1.91E-03 | 4.12E-04 |

Table 5. Plot data for EPS 8-hour trend, Figure 4.

| FY/Source | Regression Curve Data Points | | | Plot Trend Error Bar Points | | |
|------------|------------------------------|---------------|----------------|-----------------------------|----------------|----------|
| | Mean | Lower (5%) | Upper (95%) | Lower (5%) | Upper (95%) | Mean |
| SPAR/ EPIX | | | | 1.01E-05 | 3.50E-03 | 9.03E-04 |
| 1998 | 1.05E-03 | 9.16E-04 | 1.20E-03 | 1.04E-05 | 4.99E-03 | 1.21E-03 |
| 1999 | 1.07E-03 | 9.50E-04 | 1.21E-03 | 1.10E-05 | 4.20E-03 | 1.07E-03 |
| 2000 | 1.09E-03 | 9.84E-04 | 1.21E-03 | 1.02E-05 | 3.76E-03 | 9.63E-04 |
| 2001 | 1.11E-03 | 1.02E-03 | 1.22E-03 | 1.01E-05 | 3.93E-03 | 9.91E-04 |
| 2002 | 1.13E-03 | 1.05E-03 | 1.23E-03 | 1.08E-05 | 4.20E-03 | 1.07E-03 |
| 2003 | 1.16E-03 | 1.07E-03 | 1.24E-03 | 1.12E-05 | 4.86E-03 | 1.20E-03 |
| 2004 | 1.18E-03 | 1.09E-03 | 1.27E-03 | 1.06E-05 | 5.98E-03 | 1.44E-03 |
| 2005 | 1.20E-03 | 1.11E-03 | 1.30E-03 | 1.09E-05 | 4.32E-03 | 1.09E-03 |
| 2006 | 1.22E-03 | 1.12E-03 | 1.34E-03 | 1.14E-05 | 4.77E-03 | 1.19E-03 |
| 2007 | 1.25E-03 | 1.13E-03 | 1.38E-03 | 1.19E-05 | 5.02E-03 | 1.26E-03 |
| 2008 | 1.27E-03 | 1.13E-03 | 1.43E-03 | 1.24E-05 | 5.35E-03 | 1.33E-03 |
| 2009 | 1.30E-03 | 1.13E-03 | 1.49E-03 | 1.25E-05 | 4.98E-03 | 1.27E-03 |

Table 6. Basic event reliability trending data.

| Failure Mode | Component | Year | Number of Failures | Demands/Run Hours | Bayesian Update | | | Distribution |
|--------------|-----------|------|--------------------|-------------------|-----------------|--------|---------|--------------|
| | | | | | Mean | Post A | Post B | |
| FTLR | GEN | 1998 | 18 | 3854.93 | 4.48E-03 | 19.5 | 4336.9 | Beta |
| FTLR | GEN | 1999 | 8 | 3816.83 | 2.20E-03 | 9.5 | 4308.8 | Beta |
| FTLR | GEN | 2000 | 12 | 3866.97 | 3.09E-03 | 13.5 | 4355.0 | Beta |
| FTLR | GEN | 2001 | 8 | 3742.23 | 2.24E-03 | 9.5 | 4234.2 | Beta |
| FTLR | GEN | 2002 | 18 | 3856.04 | 4.48E-03 | 19.5 | 4338.0 | Beta |
| FTLR | GEN | 2003 | 16 | 3779.31 | 4.09E-03 | 17.5 | 4263.3 | Beta |
| FTLR | GEN | 2004 | 14 | 3833.4 | 3.58E-03 | 15.5 | 4319.4 | Beta |
| FTLR | GEN | 2005 | 11 | 3818.24 | 2.89E-03 | 12.5 | 4307.2 | Beta |
| FTLR | GEN | 2006 | 16 | 3715.96 | 4.15E-03 | 17.5 | 4200.0 | Beta |
| FTLR | GEN | 2007 | 19 | 3700.19 | 4.88E-03 | 20.5 | 4181.2 | Beta |
| FTLR | GEN | 2008 | 15 | 3733.92 | 3.90E-03 | 16.5 | 4218.9 | Beta |
| FTLR | GEN | 2009 | 15 | 3622.19 | 4.00E-03 | 16.5 | 4107.2 | Beta |
| FTR | GEN | 1998 | 4 | 11016.84 | 4.44E-04 | 6.0 | 13516.8 | Gamma |
| FTR | GEN | 1999 | 0 | 10976.29 | 1.48E-04 | 2.0 | 13476.3 | Gamma |
| FTR | GEN | 2000 | 5 | 12218.97 | 4.76E-04 | 7.0 | 14719.0 | Gamma |
| FTR | GEN | 2001 | 4 | 12333.93 | 4.04E-04 | 6.0 | 14833.9 | Gamma |
| FTR | GEN | 2002 | 6 | 12829.33 | 5.22E-04 | 8.0 | 15329.3 | Gamma |
| FTR | GEN | 2003 | 8 | 12229.36 | 6.79E-04 | 10.0 | 14729.4 | Gamma |
| FTR | GEN | 2004 | 9 | 11720.92 | 7.74E-04 | 11.0 | 14220.9 | Gamma |
| FTR | GEN | 2005 | 12 | 12363.5 | 9.42E-04 | 14.0 | 14863.5 | Gamma |
| FTR | GEN | 2006 | 9 | 11464.11 | 7.88E-04 | 11.0 | 13964.1 | Gamma |
| FTR | GEN | 2007 | 13 | 11691.4 | 1.06E-03 | 15.0 | 14191.4 | Gamma |
| FTR | GEN | 2008 | 15 | 11728.28 | 1.19E-03 | 17.0 | 14228.3 | Gamma |
| FTR | GEN | 2009 | 16 | 11676.54 | 1.27E-03 | 18.0 | 14176.5 | Gamma |
| FTS | GEN | 1998 | 16 | 4682.44 | 3.48E-03 | 17.0 | 4865.4 | Beta |
| FTS | GEN | 1999 | 12 | 4648.72 | 2.68E-03 | 13.0 | 4835.7 | Beta |
| FTS | GEN | 2000 | 10 | 4548.06 | 2.32E-03 | 11.0 | 4737.1 | Beta |
| FTS | GEN | 2001 | 11 | 4503.42 | 2.55E-03 | 12.0 | 4691.4 | Beta |
| FTS | GEN | 2002 | 15 | 4718.37 | 3.25E-03 | 16.0 | 4902.4 | Beta |
| FTS | GEN | 2003 | 19 | 4413.4 | 4.34E-03 | 20.0 | 4593.4 | Beta |
| FTS | GEN | 2004 | 13 | 4384.93 | 3.05E-03 | 14.0 | 4570.9 | Beta |
| FTS | GEN | 2005 | 16 | 4393.35 | 3.70E-03 | 17.0 | 4576.4 | Beta |
| FTS | GEN | 2006 | 11 | 4311.52 | 2.66E-03 | 12.0 | 4499.5 | Beta |
| FTS | GEN | 2007 | 8 | 4345.76 | 1.98E-03 | 9.0 | 4536.8 | Beta |
| FTS | GEN | 2008 | 15 | 4392.56 | 3.48E-03 | 16.0 | 4576.6 | Beta |
| FTS | GEN | 2009 | 11 | 4199.76 | 2.73E-03 | 12.0 | 4387.8 | Beta |

Table 7. Basic event UA trending data.

| Failure Mode | Component | Year | UA Hours | Critical Hours | Bayesian Update | | | |
|--------------|-----------|------|----------|----------------|-----------------|--------|--------|--------------|
| | | | | | Mean | Post A | Post B | Distribution |
| UA | EDG | 1998 | 15979.79 | 1388150 | 1.26E-02 | 0.5 | 41.7 | Beta |
| UA | EDG | 1999 | 23206.66 | 1985627 | 1.17E-02 | 1.6 | 138.3 | Beta |
| UA | EDG | 2000 | 18405.18 | 2051800 | 9.05E-03 | 1.8 | 198.2 | Beta |
| UA | EDG | 2001 | 19096.42 | 2063455 | 9.37E-03 | 1.1 | 112.8 | Beta |
| UA | EDG | 2002 | 23650.57 | 2087422 | 1.14E-02 | 1.4 | 118.8 | Beta |
| UA | EDG | 2003 | 27824.23 | 2051652 | 1.37E-02 | 0.9 | 67.1 | Beta |
| UA | EDG | 2004 | 30925.8 | 2102001 | 1.48E-02 | 0.4 | 24.7 | Beta |
| UA | EDG | 2005 | 24607.26 | 2059515 | 1.20E-02 | 1.4 | 114.0 | Beta |
| UA | EDG | 2006 | 28741.45 | 2096727 | 1.38E-02 | 1.1 | 78.1 | Beta |
| UA | EDG | 2007 | 31474.63 | 2091220 | 1.52E-02 | 1.2 | 77.8 | Beta |
| UA | EDG | 2008 | 34591.47 | 2088040 | 1.67E-02 | 1.2 | 71.3 | Beta |
| UA | EDG | 2009 | 33190.66 | 2086914 | 1.60E-02 | 1.7 | 104.3 | Beta |

Table 8. Failure mode acronyms.

| Failure Mode | Failure Mode Description |
|--------------|--|
| FTLR | Fail to Load/Run |
| FTOC | Fail to Operate |
| FTR | Fail to Run |
| FTR<1H | Fail to Run <1H |
| FTS | Fail to Start |
| SO | Spurious Operation |
| UA | Unavailability (Maintenance or State of another component) |

7 EPS SYSTEM DESCRIPTION

The EPS is designed to provide backup, onsite ac power to vital buses given a LOOP until offsite power can be restored to the plant. EPS designs vary widely among the 104 U.S. commercial nuclear power plants. A summary of those designs is presented in Table 9. Typical EPS designs include two, three, or four EDGs, with only one of the EDGs required for success. However, as indicated in Table 9, there are many variations of these typical designs, including shared EDGs and/or the ability to cross-tie to other EDGs (at multi-plant sites), and availability of alternate ac sources such as gas turbine generators (GTGs) or hydro turbine generators (HTGs). In addition, several of the plants require two EDGs for long-term success, rather than one.

SPAR modeling of the EPS incorporates the plant-to-plant design and operational differences indicated in Table 9. Table 9 shows the generating equipment used in the SPAR EPS model. In some cases, two models use the same equipment. These are repeated for each entry to show how the SPAR models calculate. All ac emergency power sources that either are automatically started and aligned to essential buses given a LOOP or can be manually started and aligned within approximately 30 minutes are included in the SPAR EPS fault trees. Additional emergency power sources such as GTGs or HTGs that require more than 30 minutes to start and align to essential buses are included in other parts of the SBO event tree, typically as additional credit for recovery of ac power. Included in the SPAR EPS fault trees are dependencies such as room cooling, service water cooling, and DC power.

Table 9. EPS configurations at U.S. commercial nuclear power plants.

| Class | Plant | Total | 1E Generator | 1E X-tie | Non-1E Generator |
|---------|-----------------|-------|--------------|----------|------------------|
| Class 2 | Beaver Valley 1 | 2 | 2 | | |
| Class 2 | Brunswick 1 | 4 | 2 | 2 | |
| Class 2 | Brunswick 2 | 4 | 2 | 2 | |
| Class 2 | Callaway | 2 | 2 | | |
| Class 2 | Clinton 1 | 2 | 2 | | |
| Class 2 | Columbia 2 | 2 | 2 | | |
| Class 2 | Comanche Peak 1 | 2 | 2 | | |
| Class 2 | Comanche Peak 2 | 2 | 2 | | |
| Class 2 | Cook 1 | 2 | 2 | | |
| Class 2 | Cook 2 | 2 | 2 | | |
| Class 2 | Cooper | 2 | 2 | | |
| Class 2 | Crystal River 3 | 2 | 2 | | |
| Class 2 | Davis-Besse | 2 | 2 | | |
| Class 2 | Duane Arnold | 2 | 2 | | |
| Class 2 | Fort Calhoun | 2 | 2 | | |
| Class 2 | Ginna | 2 | 2 | | |
| Class 2 | Grand Gulf | 2 | 2 | | |
| Class 2 | Harris | 2 | 2 | | |
| Class 2 | Kewaunee | 2 | 2 | | |
| Class 2 | McGuire 1 | 2 | 2 | | |
| Class 2 | McGuire 2 | 2 | 2 | | |
| Class 2 | Monticello | 2 | 2 | | |
| Class 2 | Nine Mile Pt. 1 | 2 | 2 | | |
| Class 2 | Nine Mile Pt. 2 | 2 | 2 | | |
| Class 2 | Oconee 1 | 2 | 1 | 1 | |
| Class 2 | Oconee 2 | 2 | 1 | 1 | |
| Class 2 | Oconee 3 | 2 | 1 | 1 | |
| Class 2 | Oyster Creek | 2 | 2 | | |
| Class 2 | Palisades | 2 | 2 | | |

Table 9. EPS configurations at U.S. commercial nuclear power plants.

| Class | Plant | Total | 1E Generator | 1E X-tie | Non-1E Generator |
|---------|------------------|-------|--|----------------------------|------------------|
| Class 2 | Perry | 2 | 2 | | |
| Class 2 | Pilgrim | 2 | 2 | | |
| Class 2 | River Bend | 3 | 3 (C EDG is different) | | 1 |
| Class 2 | Robinson 2 | 3 | 2 | | 1 |
| Class 2 | Seabrook | 2 | 2 | | |
| Class 2 | Summer | 2 | 2 | | |
| Class 2 | Vermont Yankee | 2 | 2 | | |
| Class 2 | Waterford 3 | 2 | 2 | | |
| Class 2 | Wolf Creek | 2 | 2 | | |
| Class 3 | Arkansas 1 | 3 | 2 | | 1 |
| Class 3 | Arkansas 2 | 3 | 2 | | 1 |
| Class 3 | Beaver Valley 2 | 4 | 2 | 2 | |
| Class 3 | Braidwood 1 | 4 | 4 | | |
| Class 3 | Braidwood 2 | 4 | 4 | | |
| Class 3 | Byron 1 | 4 | 2 | 2 | |
| Class 3 | Byron 2 | 4 | 2 | 2 | |
| Class 3 | Calvert Cliffs 1 | 5 | 2 | 2 | 1 |
| Class 3 | Calvert Cliffs 2 | 5 | 2 | 2 | 1 |
| Class 3 | Catawba 1 | 4 | 2 | 2 | |
| Class 3 | Catawba 2 | 4 | 2 | 2 | |
| Class 3 | Diablo Canyon 1 | 3 | 3 | | |
| Class 3 | Diablo Canyon 2 | 3 | 3 | | |
| Class 3 | Farley 1 | 5 | 3 | 2 | |
| Class 3 | Farley 2 | 5 | 3 | 2 | |
| Class 3 | Hatch 1 | 5 | 3 | 2 | |
| Class 3 | Hatch 2 | 5 | 3 | 2 | |
| Class 3 | Hope Creek | 4 | 4 | | |
| Class 3 | Indian Point 2 | 3 | 3 | | |
| Class 3 | Indian Point 3 | 3 | 3 | | |
| Class 3 | La Salle 1 | 4 | 2 | 2 | |
| Class 3 | La Salle 2 | 4 | 2 | 2 | |
| Class 3 | Millstone 2 | 3 | 2 | | 1 |
| Class 3 | Millstone 3 | 3 | 2 | | 1 |
| Class 3 | Palo Verde 1 | 8 | 2 | 4 (not effective in model) | 2 (need both) |
| Class 3 | Palo Verde 2 | 8 | 2 | 4 (not effective in model) | 2 (need both) |
| Class 3 | Palo Verde 3 | 8 | 2 | 4 (not effective in model) | 2 (need both) |
| Class 3 | Peach Bottom 2 | 4 | 4 (2 of 4) | | |
| Class 3 | Peach Bottom 3 | 4 | 4 (2 of 4) | | |
| Class 3 | Salem 1 | 4 | 3 | | 1 |
| Class 3 | Salem 2 | 4 | 3 | | 1 |
| Class 3 | San Onofre 2 | 4 | 2 | 2 | |
| Class 3 | San Onofre 3 | 4 | 2 | 2 | |
| Class 3 | Sequoyah 1 | 4 | 2 | 2 | |
| Class 3 | Sequoyah 2 | 4 | 2 | 2 | |
| Class 3 | South Texas 1 | 3 | 3 | | |
| Class 3 | South Texas 2 | 3 | 3 | | |
| Class 3 | St. Lucie 1 | 4 | 2 | 2 | |
| Class 3 | St. Lucie 2 | 4 | 2 | 2 | |
| Class 3 | Surry 1 | 4 | 3 | | 1 |
| Class 3 | Surry 2 | 4 | 3 | | 1 |
| Class 3 | Susquehanna 1 | 5 | 5 (2 of the EDGs cannot support all loads) | | |

Table 9. EPS configurations at U.S. commercial nuclear power plants.

| Class | Plant | Total | 1E Generator | 1E X-tie | Non-1E Generator |
|---------|------------------|-------|--|----------|------------------|
| Class 3 | Susquehanna 2 | 5 | 5 (2 of the EDGs cannot support all loads) | | |
| Class 3 | Three Mile Isl 1 | 3 | 2 | | 1 |
| Class 3 | Turkey Point 3 | 4 | 2 | 2 | |
| Class 3 | Turkey Point 4 | 4 | 2 | 2 | |
| Class 3 | Vogtle 1 | 3 | 2 | 1 | |
| Class 3 | Vogtle 2 | 3 | 2 | 1 | |
| Class 3 | Watts Bar 1 | 4 | 2 | 2 | |
| Class 4 | Browns Ferry 1 | 8 | 4 | 4 | |
| Class 4 | Browns Ferry 2 | 6 | 4 | 2 | |
| Class 4 | Browns Ferry 3 | 8 | 4 | 4 | |
| Class 4 | Dresden 2 | 5 | 2 | 1 | 2 |
| Class 4 | Dresden 3 | 5 | 2 | 1 | 2 |
| Class 4 | Fermi 2 | 9 | 4 | | 5 |
| Class 4 | FitzPatrick | 4 | 4 | | |
| Class 4 | Limerick 1 | 6 | 4 | 2 | |
| Class 4 | Limerick 2 | 6 | 4 | 2 | |
| Class 4 | North Anna 1 | 5 | 2 | 2 | 1 |
| Class 4 | North Anna 2 | 5 | 2 | 2 | 1 |
| Class 4 | Point Beach 1 | 5 | 4 | | 1 |
| Class 4 | Point Beach 2 | 5 | 4 | | 1 |
| Class 4 | Prairie Island 1 | 4 | 2 | 2 | |
| Class 4 | Prairie Island 2 | 4 | 2 | 2 | |
| Class 4 | Quad Cities 1 | 5 | 1 | 2 | 2 |
| Class 4 | Quad Cities 2 | 5 | 1 | 2 | 2 |

The typical EPS consists of two or more emergency power sources, usually diesel generators, connected to two or more vital or safety buses. These vital buses power equipment needed for safe shutdown during most transients that are postulated at nuclear power plants.

Figure 9 shows the simplest EPS configuration. Variations are: more buses, usually with their own emergency power sources, swing power sources that can power vital buses at either of two units, and alternate emergency power sources typically referred to as station blackout generators.

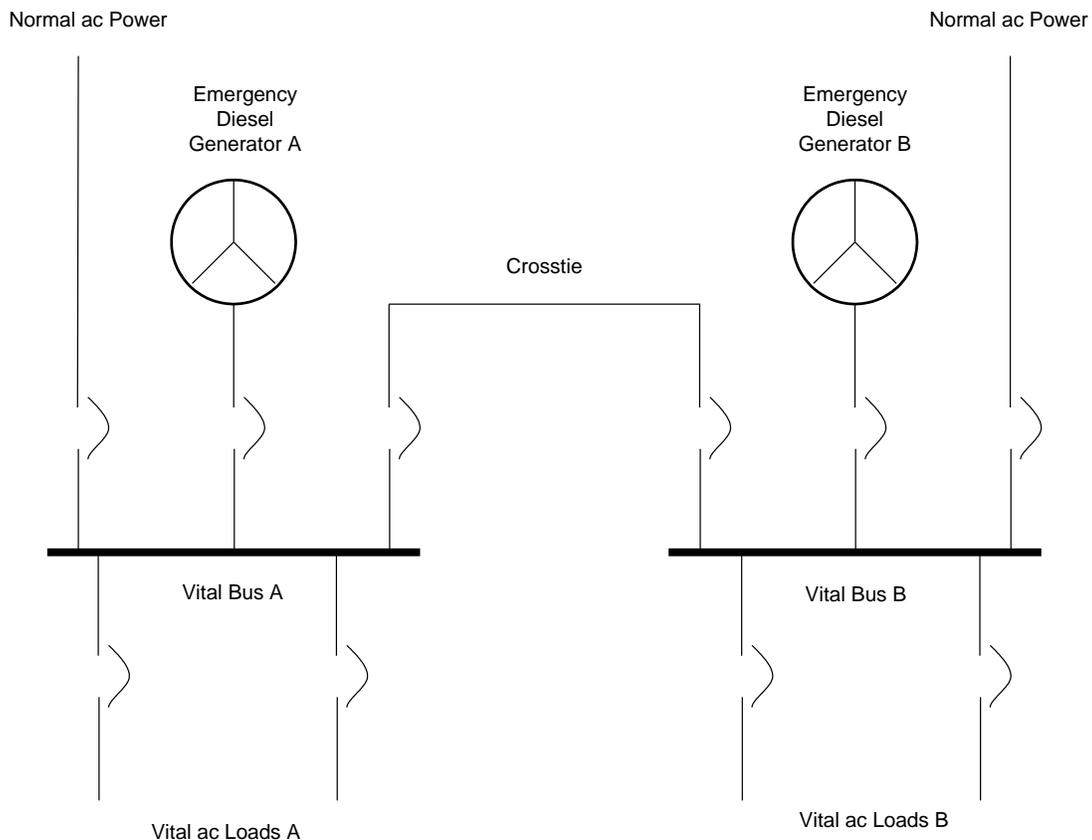


Figure 9. Simplified EPS system schematic.

The SPAR models of the EPS include many more components than those shown in Figure 9. Most of these components are related to the support needed for the emergency power source success. Some of these are explicitly modeled in SPAR if there is a common-mode failure of multiple generators. Generally, these include:

- **Cooling**—Cooling is required to remove heat from the lubricating oil and the engine itself. Cooling is provided by service water either directly or through a closed loop cooling system such as component cooling water. Some emergency power sources have dedicated cooling systems that are independent of the service water systems.
- **Room Cooling**—Room cooling is usually required for extended performance of the EPS. The room cooling is provided by air conditioning heat exchangers that may be cooled by a chilled water source.
- **Fuel Oil**—Fuel oil is usually provided from a common fuel oil tank to separate ‘day tanks’ for each emergency power source. Pumps, valves, and instrumentation are required to maintain day tank levels and to supply fuel oil to the engine itself.
- **Sequencer**—The sequencer strips loads from the dead bus prior to attempting to load the bus with the emergency power source. Then the sequencer sequences loads back onto the bus once it has been re-energized.

- DC Power—DC power is provided by the vital batteries. DC power provides the energy to operate breakers and powers the control circuitry for the EPS.

8 REFERENCE

1. S.A. Eide, et al, *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, February 2007.